(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 117 197 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
04.06.2008 Bulletin 2008/23

(51) Int Cl.:
H04B 7/06 (2006.01)

(21) Application number: **00311058.2**

(22) Date of filing: **12.12.2000**

(54) **Space-time processing for multiple-input multiple-output wireless communication systems**

Raum-Zeit-Verarbeitung für drahtlose Kommunikationssysteme mit mehreren Eingängen und mehreren Ausgängen

Traitement spatio-temporel pour des systèmes de communication sans fil à entrées multiples et sorties multiples

(84) Designated Contracting States:
DE FI FR GB SE

(30) Priority: **13.01.2000 US 482429**

(43) Date of publication of application:
18.07.2001 Bulletin 2001/29

(73) Proprietor: **Lucent Technologies Inc.**
Murray Hill, New Jersey 07974-0636 (US)

(72) Inventors:
- **Foschini, Gerard Joseph**
Sayerville,
New Jersey 08879 (US)
- **Lozano, Angel**
Holmdel,
New Jersey 07733 (US)
- **Rashid-Farrokhi, Farrokh**
Manalapan,
New Jersey 07726 (US)
- **Valenzuela, Reinaldo A.**
Holmdel,
New Jersey 07733 (US)

(74) Representative: **Sarup, David Alexander et al**
Alcatel-Lucent Telecom Limited
Unit 18, Core 3,
Workzone
Innova Business Park
Electric Avenue
Enfield, EN3 7XU (GB)

(56) References cited:
EP-A- 0 807 989
EP-A- 0 951 091
WO-A-98/09381
US-A- 5 471 647

EP 1 117 197 B1

Description

Technical Field

[0001] This invention relates to the art of wireless communications, and more particularly, to wireless communication systems using multiple antennas at the transmitter and multiple antennas at the receivers, so called multiple-input, multiple-output (MIMO) systems.

Background of the Invention

[0002] It is well known in the art that multiple-input, multiple-output (MIMO) systems can achieve dramatically improved capacity as compared to single antenna, i.e., single antenna to single antenna or multiple antenna to single antenna, systems. However, to achieve this improvement, it is preferable that there be a rich scattering environments, so that the various signals reaching the multiple receive antennas be largely uncorrelated. If the signals have some degree of correlation, and such correlation is ignored, performance degrades and capacity is reduced.

[0003] WO 98/09381 teaches a wireless communication system that couples an adaptive array of antenna elements at a base station with an adaptive array of antenna elements at a subscriber unit.

Summary of the Invention

[0004] Methods and apparatus according to the invention are as set out in the independent claims. Preferred forms are set out in the dependent claims.

[0005] We have invented a way of developing signals in a MIMO system such that even in the face of some correlation so as to obtain the most performance and capacity that can be achieved with a channel of that level of correlation. In accordance with the principles of the invention, the signals transmitted from the various antennas are processed so as to improve the ability of the receiver to extract them from the received signal. More specifically the number of bit streams that is transmitted simultaneously is adjusted, e.g., reduced, depending on the level of correlation, while multiple versions of each bit stream, variously weighted, are transmitted simultaneously. The variously weighted versions are combined to produced one combined weighted signal, a so-called "transmit vector", for each antenna. The receiver processes the received signals in the same manner as it would have had all the signals reaching the receive antennas been uncorrelated.

[0006] In one embodiment of the invention, the weight vectors are determined by the forward channel transmitter using the channel properties of the forward link which are made known to the transmitter of the forward link by being transmitted from the receiver of the forward link by the transmitter of the reverse link. In another embodiment of the invention the weight vectors are determined by the forward channel receiver using the channel properties of the forward link and the determined weight vectors are made known to the transmitter of the forward link by being transmitted from the receiver of the forward link by the transmitter of the reverse link.

[0007] The channel properties used to determine the weight vectors may include the channel response from the transmitter to the receiver and the covariance matrix of noise and interference measured at the receiver.

Brief Description of the Drawing

[0008] In the drawing:

FIG. 1 shows an exemplary portion of a transmitter for developing signals to transmit in a MIMO system such that even in the face of some correlation the most performance and capacity that can be achieved with a channel of that level of correlation is obtained, in accordance with the principles of the invention;

FIG. 2 shows an exemplary portion of a receiver for a MIMO system arranged in accordance with the principles of the invention; and

FIG. 3 shows an exemplary process, in flow chart form, for developing signals to transmit in a MIMO system such that even in the face of some correlation the most performance and capacity that can be achieved with a channel of that level of correlation is obtained, in accordance with the principles of the invention;

FIG. 4 shows another exemplary process, in flow chart form, for developing signals to transmit in a MIMO system such that even in the face of some correlation the most performance and capacity that can be achieved with a channel of that level of correlation is obtained, in accordance with the principles of the invention.

Detailed Description

[0009] It will be appreciated by those skilled in the art that the block diagrams herein represent conceptual views of illustrative circuitry embodying the principles of the invention. Similarly, it will be appreciated that any flow charts, flow diagrams, state transition diagrams, pseudocode, and the like represent various processes which may be substantially represented in computer readable medium and so executed by a computer or processor, whether or not such computer or processor is explicitly shown.

[0010] The functions of the various elements shown in the FIGs., including functional blocks labeled as "processors" may be provided through the use of dedicated hardware as well as hardware capable of executing software in association with appropriate software. When provided by a processor, the functions may be provided by a single dedicated processor, by a single shared processor, or by a plurality of individual processors, some of

which may be shared. Moreover, explicit use of the term "processor" or "controller" should not be construed to refer exclusively to hardware capable of executing software, and may implicitly include, without limitation, digital signal processor (DSP) hardware, read-only memory (ROM) for storing software, random access memory (RAM), and non-volatile storage. Other hardware, conventional and/or custom, may also be included. Similarly, any switches shown in the FIGS. are conceptual only. Their function may be carried out through the operation of program logic, through dedicated logic, through the interaction of program control and dedicated logic, or even manually, the particular technique being selectable by the implementor as more specifically understood from the context.

[0011] FIG. 1 shows an exemplary portion of a transmitter for developing signals to transmit in a MIMO system having a transmitter with N transmit antennas transmitting over a forward channel to a receiver having L receiver antennas and a reverse channel for communicating from said receiver to said transmitter, such that even in the face of some correlation the most performance and capacity that can be achieved with a channel of that level of correlation is obtained, in accordance with the principles of the invention. Shown in FIG. 1 are a) demultiplexer (demux) 101; b) antenna signal developers 103, including antenna signal developers 103-1 through 103-N; c) weight supplier 105; d) N antennas 107, including antennas 107-1 through 107-N; e) digital-to-analog converters (DAC) 115, including 115-1 through 115-N; and f) upconverters 117, including upconverters 117-1 through 117-N.

[0012] Demultiplexer 101 takes a data stream as an input and supplies as an output data substreams by supplying various bits from the input data stream to each of the data substreams. One data substream may be supplied by demultiplexer 101 to one of N outputs. However, when the number of uncorrelated signals that can be transmitted is reduced, the number of bit streams that are transmitted simultaneously is reduced to match the number of uncorrelated signals that can be transmitted. In such a case, the particular outputs utilized is at the discretion of the implementor. For example, only the first Y outputs, where Y is the number of uncorrelated signals that can be transmitted, are employed.

[0013] Each data substream is supplied to a corresponding one of antenna signal developers 103. Each one of antenna signal developers 103 includes one of weight blocks 109-1 through 109-N and one of adders 111-1 through 111-N. Within each of antenna signal developers 103 the data substream is supplied to each of multipliers 113 within the one of weight blocks 109 therein.

[0014] Weight supplier 105 supplies weight values to each of multipliers 113. In one embodiment of the invention weight supplier 105 actually develops the weight values in response to information received via the reverse channel from the receiver (not shown). In another embodiment of the invention the weight values are developed in the receiver, then supplied via the reverse channel to the transmitter, in which they are stored in weight supplier 105 until such time as they are required. A process for developing the weights in accordance with an aspect of the invention will be described hereinbelow.

[0015] Each of multipliers 113 multiplies the substream it receives by the weight it receives. The resulting product is supplied to a respective one of adders 111. More specifically, the product supplied by the Rth multiplier of each weight block 109, where R is from 1 to N, is supplied to the Rth one of adders 111. For those multipliers that are not supplied with a substream, their output is insured to be zero (0), by any technique desired by the implementor.

[0016] Each of adders 111 adds the signals input to it and supplies the resulting sum as an output to its associated respective one of DACs 115. Each of DACs 115 takes the digital signal it receives from one of adders 111 and converts it to an analog baseband signal. The analog baseband signal produced by each of DACs 115 is supplied to a respective one of upconverters 117, which upconverts the baseband analog signal to a radio frequency signal. The radio frequency signals produced by upconverters 117 are supplied to respective ones of antennas 107 for broadcast to a receiver.

[0017] FIG. 2 shows an exemplary portion of a receiver for a MIMO system arranged in accordance with the principles of the invention. FIG. 2 shows a) L antennas 201, including antennas 201-1 through 201-L; b) downconverters 203, including downconverters 203-1 through 203-L; c) analog-to-digital converters (ADCs) 205, including analog-to-digital converters 205-1 through 205-L; d) estimate interference covariance matrix and channel response unit 207; e) optional weight calculator 209; and f) optional switch 211.

[0018] Each of antennas 201 receives radio signals and supplies an electrical version thereof to its respective, associated one of downconverters 203. Each of downconverters 203 downconverts the signal it receives to baseband, and supplies the resulting baseband signal to its associated one of ADCs 205. Each of ADCs 205 converts the baseband analog signal it received to a digital representation and supplies the digital representation to estimate interference covariance matrix and channel response unit 207.

[0019] Estimate interference covariance matrix and channel response unit 207 develops an estimate of the interference covariance matrix and an estimate of the forward matrix channel response in the conventional manner. Note that matrices are required because there are multiple transmit antennas and multiple receive antennas.

[0020] The estimate of the interference covariance matrix and an estimate of the forward matrix channel response are supplied either to optional weight calculator 209 or they are supplied for via the reverse channel to the transmitter (FIG. 1). If the estimate of the interference covariance matrix and an estimate of the forward matrix

channel response is supplied to weight calculator 209, weight calculator determines the weight values that are to be used, in accordance with an aspect of the invention and as described hereinbelow, and supplies the resulting weight values to the transmitter (FIG. 1) via the reverse channel.

[0021] FIG. 3 shows an exemplary process, in flow chart form, for developing signals to transmit in a MIMO system having a transmitter with N transmit antennas transmitting over a forward channel to a receiver having L receiver antennas and a reverse channel for communicating from said receiver to said transmitter, such that even in the face of some correlation the most performance and capacity that can be achieved with a channel of that level of correlation is obtained, in accordance with the principles of the invention. The process of FIG. 3 may be employed in an embodiment of the invention that uses the hardware of FIGs. 1 and 2, with switch 211 being connected to estimate interference covariance matrix and channel response unit 207 and with a communication protocol as follows. First it is necessary to determine the length of time during which the channel characteristics are stable. This is typically performed at the system engineering phase of developing the system, using measurements of the environment into which the system is to be deployed, as is well known by those of ordinary skill in the art. Once the length of time for which the channel characteristics are stable is known, that time is considered as a frame, and the frame is divided into time slots. Each frame has a preamble, which may occupy one or more of the time slots. The frames, and accordingly the time slots, are repeating in nature.

[0022] The process of FIG. 3 is entered in step 301 at the beginning of each frame. Next, in step 303, the interference covariance matrix K^N and channel response H at the receiver are determined, e.g., in the receiver of the forward link, such as in interference covariance matrix and channel response unit 207 (FIG. 2). Thereafter, in step 305, (FIG. 3) interference covariance matrix K^N and channel response matrix H are supplied by the receiver of the forward link to the transmitter of forward link, e.g., via the reverse channel.

[0023] In step 307 weights $w_i = [w_{i1}, \ldots, w_{iN}]$ are calculated, e.g., by weight supplier 105 (FIG. 1), where i is an integer ranging from 1 to N. More specifically, the weights are calculated as follows. First the matrix equation $H^\dagger(K^N)H = U^\dagger\Lambda^2U$ is solved, where:

a) H is the channel response matrix;
b) $H^\dagger$ is the conjugate transpose of channel response matrix H, † being the well known symbol for conjugate transpose;
c) K^N is the interference covariance matrix;
d) U is a unitary matrix, each column of which is an eigenvector of $H^\dagger(K^N)H$;
e) Λ is a diagonal matrix defined as $\Lambda = diag(\lambda^1, \ldots \lambda^M)$, where $\lambda^1 \ldots\ldots \lambda^M$ are each eigenvalues of $H^\dagger(K^N)H$, M being the maximum number of nonzero eigenvalues, which corresponds to the number of substreams that actually can be used; and
f) $U^\dagger$ is the conjugate transpose of matrix U.

[0024] Then well known, so-called "waterfilling" is performed on the eigenvalues λ by solving the simultaneous equations $\tilde{\lambda}^k = (\nu - \frac{1}{(\lambda^k)^2})^+$ and $\sum_k \tilde{\lambda}^k = P$, for ν, where:

k is an integer index that ranges from 1 to M;
P is the transmitted power;
+ is an operator that returns zero (0) when its argument is negative, and returns the argument itself when it is positive; and
each λ is an intermediate variable representative of a power for each weight vector.

[0025] A new matrix Φ is defined as $\Phi = U^\dagger\, diag(\tilde{\lambda}^1, \ldots \tilde{\lambda}^M)\, U$, where *diag* indicates that the various $\tilde{\lambda}$ are arranged as the elements of the main diagonal of the matrix, all other entries being zero (0). Each column of matrix Φ is used as a normalized, i.e., based on unit power, weight vector as indicated by $\Phi = [z_1, \ldots, z_N]$ and the weight vectors are made up of individual weights z, $z_i = [z_{i1}, \ldots, z_{iN}]$. The weight vector $w_i = [w_{i1}, \ldots, w_{iN}]$ is then determined by unnormalizing, based on the power to be assigned to the weight vector, the various weights therein, being $\sqrt{\tilde{\lambda}^i}\, z_{ij}$, where j is an integer ranging from1 to N.

[0026] In step 309 the input data stream, S(t) (FIG. 1), is divided into N substreams $S_1 \ldots S_N$, e.g., by demultiplexer 101. Each of the data streams is then multiplied by a respective one of weight vectors $w_{i1}, \ldots, w_{iN}$, in step 311 (FIG. 3). In other words, each bit of each particular data stream is multiplied by each of the weights in its respective weight vector to produce N weighted bits for each data stream.

[0027] In step 313 the weighted bits for each of the substreams is combined by each antenna adder, e.g., adders 111. In this regard, the weighted bit produced for each substream from the first weight is added at the adder of the first antenna, the weighted bit produced for each substream from the second weight is added at the adder of the second antenna, and so forth, as indicated in FIG. 1. As will be readily apparent from the foregoing, any substream greater in number than M will be zero, since M corresponds to the number of substreams that actually can be used. Such zero substreams do not contribute to the sum produced by adders 111.

[0028] The process then exits in step 315.

[0029] FIG. 4 shows another exemplary process, in flow chart form, for developing signals to transmit in a MIMO system having a transmitter with N transmit an-

tennas transmitting over a forward channel to a receiver having L receiver antennas and a reverse channel for communicating from said receiver to said transmitter, such that even in the face of some correlation the most performance and capacity that can be achieved with a channel of that level of correlation is obtained, in accordance with the principles of the invention. The process of FIG. 4 may be employed in an embodiment of the invention that uses the hardware of FIGs. 1 and 2, with switch 211 being connected to weight calculator 209 and with a communication protocol as described in connection with FIG. 3. Note that for the process of FIG. 4, weight supplier 105 of FIG. 1 will not compute the various weights, but will instead merely store the weights received from weight calculator 209 and supply them to the various ones of multipliers 113 as is necessary.

[0030] The process of FIG. 4 is entered in step 401 at the beginning of each frame. Next, in step 403, the interference covariance matrix K^N and channel response H at the receiver are determined, e.g., in the receiver of the forward link, such as in interference covariance matrix and channel response unit 207 (FIG. 2). In step 405 weights $w_i = [w_{i1},...w_{iN}]$ are calculated, e.g., by weight supplier 105 (FIG. 1). More specifically, the weights are calculated as follows.

[0031] First the matrix equation $H^{\dagger}(K^N)H = U^{\dagger}A^2U$ is solved, where:

a) H is the channel response matrix;
b) $H^{\dagger}$ is the conjugate transpose of channel response matrix H, † being the well known symbol for conjugate transpose;
c) K^N is the interference covariance matrix;
d) U is a unitary matrix, each column of which is an eigenvector of $H^{\dagger}(K^N)H$;
e) A is a diagonal matrix defined as $\Lambda = diag(\lambda^1,..., \lambda^M)$, where $\lambda^1,...,\lambda^M$ are each eigenvalues of $H^{\dagger}(K^N)H$, M being the maximum number of nonzero eigenvalues, which corresponds to the number of substreams that actually can be used; and
f) $U^{\dagger}$ is the conjugate transpose of matrix U.

[0032] Then well known, so-called "waterfilling" is performed on the eigenvalues λ by solving the simultaneous equations $\tilde{\lambda}^k = (\nu - \frac{1}{(\lambda^k)^2})^+$ and $\sum_k \tilde{\lambda}^k = P$, for ν, where:

k is an integer index that ranges from 1 to M;
P is the transmitted power;
+ is an operator that returns zero (0) when its argument is negative, and returns the argument itself when it is positive; and
each λ is an intermediate variable representative of a power for each weight vector.

[0033] A new matrix Φ is defined as $\Phi = U^{\dagger}\, diag(\tilde{\lambda}^1,..., \lambda^M)\, U$, where *diag* indicates that the various λ are arranged as the elements of the main diagonal of the matrix, all other entries being zero (0). Each column of matrix Φ is used as a normalized, i.e., based on unit power, weight vector as indicated by $\Phi=[z_1,...,z_N]$ and the weight vectors are made up of individual weights z, $z_i = [z_{i1},..., z_{tN}]$. The weight vector $W_i = [w_{i1}..., w_{iN}]$ is then determined by unnormalizing, based on the power to be assigned to the weight vector, the various weights therein being $\sqrt{\tilde{\lambda}^i}\, z_{ij}$, where *j* is an integer ranging from 1 to N.

[0034] Thereafter, in step 407, the determined weight values are supplied by the receiver of the forward link to the transmitter of forward link, e.g., via the reverse channel. The weights are stored in weight supplier 105 (FIG. 1)

[0035] In step 409 (FIG. 4) the input data stream, S(t) (FIG. 1), is divided into N substreams S_1, ... S_N, e.g., by demultiplexer 101. Each of the data streams is then multiplied by a respective one of weight vectors $w_{i1},..., w_{iN}$, in step 411 (FIG. 4), where i is an integer ranging from 1 to N. In other words, each bit of each particular data stream is multiplied by each of the weights in its respective weight vector to produce N weighted bits for each data stream.

[0036] In step 413 the weighted bits for each of the substreams is combined by each antenna adder, e.g., adders 111. In this regard, the weighted bit produced for each substream from the first weight is added at the adder of the first antenna, the weighted bit produced for each substream from the second weight is added at the adder of the second antenna, and so forth, as indicated in FIG. 1. As will be readily apparent from the foregoing, any substream greater in number than M will be zero, since M corresponds to the number of substreams that actually can be used. Such zero substreams do not contribute to the sum produced by adders 111.

[0037] The process then exits in step 415.

[0038] In another embodiment of the invention, for use with so-called "time division duplex" (TDD) systems, which share a single channel for both the forward and reverse channels, the estimation of the channel response may be performed at either end of the wireless link. This is because since the forward and reverse channels share the same frequency channel, alternating between which is using the channel at any one time, then provided the time split between the forward and reverse channel is small, the channel response for the forward and reverse channels will be the same. Therefore, the receiver of the reverse channel will experience the same channel response as the receiver of the forward channel, and so the receiver of the reverse link can perform all the channel estimations that were previously performed by the receiver of the forward link. Likewise, the receiver of the forward channel will experience the same channel response as the receiver of the reverse channel, and so the receiver of the forward link can perform all the channel

estimations that were previously performed by the receiver of the reverse link.

Claims

1. A method for transmitting signals in communications system having a transmitter with N transmit antennas transmitting over a forward channel to a receiver having L receiver antennas and a reverse channel for communicating from said receiver to said transmitter, in which there may exist correlation in the signals received by two or more of said L receive antennas, the method comprising the steps of:

    determining the number of independent signals that can be transmitted from said N transmit antennas to said L receive antennas;
    creating, from a data stream, a data substream to be transmitted for each of the number of independent signals that can be transmitted from said N transmit antennas to said receive antennas;

    the method being **CHARACTERIZED by**
    weighting each of said substreams with N weights, one weight for each of said N transmit antennas, said weights being determined by said transmitter as a function of channel information and an interference covariance matrix, to produce N weighted substreams per substream;
    combining one of said weighted substreams produced from each of said substreams for each of said transmit antennas to produce a transmit signal for each of said transmit antennas.

2. The method as defined in claim 1 further comprising the step of transmitting said transmit signal from a respective one of said antennas.

3. The method as defined in claim 1 further comprising the step of receiving said weights via said reverse channel.

4. The method as defined in claim 1 wherein said channel information and said interference covariance matrix are received by said transmitter from said receiver via said rever channel

5. The method as defined in claim 1 wherein said weights are determined by
    solving a matrix equation $H^\dagger(K^N)H = U^\dagger A\ ^2U$ where:

    H is a channel response matrix,
    $H^\dagger$ is a conj ugate transpose of said channel response matrix H,
    K^N is the interference covariance matrix,
    U is a unitary matrix, each column of which is an eigenvector of $H^\dagger(K^N)H$,
    A is a diagonal matrix defined as $\Lambda = diag(\lambda^1, \ldots, \lambda^M)$, where $\lambda^1, \ldots, \lambda^M$ are each eigenvalues of $H^\dagger(K^N)H$, M being the maximum number of nonzero eigenvalues, which corresponds to the number of said independent signals, and
    $U^\dagger$ is the conjugate transpose of matrix U;
    waterfilling said eigenvalues λ by solving the simultaneous equations

    $$\tilde{\lambda}^k = \left(\nu - \frac{1}{(\lambda^k)^2}\right)^+ \text{ and } \sum_k \tilde{\lambda}^k = P,$$ for ν, where:

    k is an integer index that ranges from 1 to M,
    P is the transmitted power,
    + is an operator that returns zero 0 when its argument is negative, and returns the argument itself when it is positive, and
    each $\bar{\lambda}$ is an intermediate variable representative of a power for each weight vector;

    defining matrix Φ as $\Phi = U^\dagger diag(\bar{\lambda}^1, \ldots, \lambda^M)U$, where *diag* indicates that the various $\tilde{\lambda}$ are arranged as the elements of the main diagonal of matrix Φ;

    wherein each column of matrix Φ is used as a normalized weight vector indicated by $\Phi = [z_1, \ldots, z_N]$ and said normalized weight vectors are made up of individual normalized weights z, $z_i = [z_{i1}, \ldots, z_{iN}]$, where *i* is an integer ranging from 1 to N;
    developing an unnormalized weight vector $w_i = [w_{i1}, \ldots, w_{iN}]$, with each of said weights therein being $\sqrt{\tilde{\lambda}^i} z_{ij}$, where j is an integer ranging from 1 to N.

6. Apparatus for transmitting signals in communications system having a transmitter with N transmit antennas (107) transmitting over a forward channel to a receiver having L receiver antennas (201) and a reverse channel for communicating from said to said transmitter, in which there may exist correlation in the signals received by two or more of said L receive antennas, the apparatus comprising:

    means for determining (105, 101) the number of independent signals that can be transmitted from said N transmit antennas to said L receive antennas;
    means for creating (101), from a data stream, a data substream to be transmitted for each of the number of independent signals that can be transmitted from said N transmit antennas to said L receive antennas;

    said apparatus being **CHARACTERIZED by**

means for weighting (113) each of said substreams with N weights, one weight for each of said N transmit antennas, said weights being determined by said apparatus for transmitting signals as a function of information about said forward channel and an interference covariance matrix, to produce N weighted substreams per substream;
means for combining (111) one of said weighted substreams produced from each of said substreams for each of said antennas to produce a transmit signal for each antenna.

7. The apparatus as defined in claim 6 wherein said transmitter comprises means for developing said weights (105).

8. The apparatus as defined in claim 6 wherein said transmitter comprises means for storing said weights (105).

9. The apparatus as defined in claim 6 wherein said receiver comprises means for developing said weights (209).

10. A transmitter for transmitting signals in communications system having a transmitter with N transmit antennas (107) transmitting over a forward channel to a receiver having L receiver antennas and a reverse channel for communicating from said receiver to said transmitter, in which there may exist correlation in the signals received by two or more of said L receive antennas (201), the transmitter comprising:

a demultiplexor (101) for creating, from a data stream, a data substream to be transmitted for each of the number of independent signals that can be transmitted from said N transmit antennas to said L receive antennas;

said transmitter being **CHARACTERIZED by**
multipliers (113) for weighting each of said substreams with N weights, one weight for each of said N transmit antennas, wherein said weights are determined in said transmitter in response to an interference covariance matrix estimate and an estimate of the forward channel response between said transmitter and said receiver, to produce N weighted substreams per substream; and
adders (111) for combining one of said weighted substreams produced from each of said for each of said antennas to produce a transmit signal for each of said transmit antennas.

11. The transmitter as defined in claim 10 further comprising a digital to analog converter (115) for converting each of said combined weighted substreams.

12. The transmitter as defined in claim 10 further comprising an upconverter (117) for converting to radio frequencies each of said analog-converted combined weighted substreams.

13. The transmitter as defined in claim 10 wherein said interference covariance matrix estimate and said estimate of the forward channel response are received by said transmitter from said receiver over said reverse channel.

14. The transmitter as defined in claim 10 wherein said weights are determined in said receiver and are transmitted to said transmitter over said reverse channel.

15. The transmitter as defined in claim 10 wherein said weights are determined by
solving a matrix equation $H^{\dagger}(K^N)H = U^{\dagger}\lambda^2 U$ where:

H is a channel response matrix,
$H^{\dagger}$ is a conjugate transpose of said channel response matrix H,
K^N is the interference covariance matrix,
U is a unitary matrix, each column of which is an eigenvector of $H^{\dagger}(K^N)H$,
Λ is a diagonal matrix defined as $\Lambda = diag(\lambda^1,..., \lambda^M)$, where $\lambda^1,...,\lambda^M$ are each eigen values of $H^{\dagger}(K^N)H$, M being the maximum number of nonzero eigenvalues, which corresponds to the number of said independent signals, and
$U^{\dagger}$ is the conjugate transpose of matrix U;
waterfilling said eigenvalues λ by solving the simultaneous equations $\tilde{\lambda}^k = \left(\nu - \frac{1}{(\lambda^k)^2}\right)^+$

and $\sum_k \tilde{\lambda}^k = P$, for ν, where:

k is an integer index that ranges from 1 to M,
P is the transmitted power,
+ is an operator that returns zero 0 when its argument is negative, and returns the argument itself when it is positive, and
each $\tilde{\lambda}$, is an intermediate variable representative of a power for each weight vector;

defining matrix Φ as $\Phi = U^{\dagger}diag(\tilde{\lambda}^1,..., \lambda^M)U$, where diag indicates that the various $\tilde{\lambda}$ are arranged as the elements of the main diagonal of matrix Φ;

wherein each column of matrix Φ is used as a normalized weight vector indicated by $\Phi = [z_1,...,z_N]$ and said normalized weight vectors are made up of individual normalized weights z, $z_i = [z_{i1},...,z_{iN}]$, where i is an integer ranging from 1 to N;
developing unnormalized weight vector $w_i = (w_{t1},...,$

$w_{tN}]$, with each of said weights therein being $\sqrt{\tilde{\lambda}^i} z_{ij}$, where j is an integer ranging from 1 to N.

16. The transmitter as defined in claim 10 wherein said transmitter and receiver communicate using time division multiplexing TDD and said weights are determined in said transmitter using an estimate of the forward channel response that is determined by a receiver of said reverse link for said transmitter.

17. A receiver for use in a MIMO system, comprising:

L antennas (201);
L downconverters (203); and
an estimator for determining an estimate of an interference covariance matrix for a forward channel being received by said receiver;

said receiver being **CHARACTERIZED by** means for transmitting (211) information for use by a transmitter in weighting signals supplied to N transmit antennas of said transmitter, said information being a function of said interference covariance matrix.

18. The receiver as defined in claim 17, wherein said information is said interference covariance matrix.

19. The receiver as defined in claim 17 further comprising an estimator (207) for determining an estimate of a channel response for a forward channel being received by said receiver, wherein said information includes said estimate of a channel response for a forward channel and said interference covariance matrix.

20. The receiver as defined in claim 17 further comprising:

an estimator (207) for determining an estimate of an interference covariance for a forward channel being received by said receiver; and
a weight calculator (209) for calculating weights for use by a transmitter of said forward channel to transmit data substreams to said receiver as a function of said estimate of an interference covariance matrix for a forward channel being received by said receiver and said estimate of a channel response for a forward channel being received by said receiver;

wherein said information is said weights.

21. The receiver as defined in claim 20 wherein weights are determined in said weight calculator by solving a matrix equation $H^\dagger(K^N)H = U^\dagger\Lambda^2U$ where:

H is a channel response matrix,
$H^\dagger$ is a conjugate transpose of said channel response matrix H,
K^N is the interference covariance matrix,
U is a unitary matrix, each column of which is an eigenvector of $H^\dagger(K^N)H$,
A is a diagonal matrix defined as $\Lambda = diag(\lambda^1,\ldots,\lambda^M)$, where $\lambda^1,\ldots,\lambda^M$ are each eigenvalues of $H^\dagger(K^N)H$, M being the maximum number of nonzero eigenvalues, which corresponds to the number of said independent signals, and
$U^\dagger$ is the conjugate transpose of matrix U;
waterfilling said eigenvalues λ by solving the simultaneous equations $\tilde{\lambda}^k = (v - \frac{1}{(\lambda^k)^2})^+$ and $\sum_k \tilde{\lambda}^k = P$, for v, where:

k is an integer index that ranges from 1 to M,
P is the transmitted power,
+ is an operator that returns zero (0) when its argument is negative, and returns the argument itself when it is positive, and
each $\tilde{\lambda}$, is an intermediate variable representative of a power for each weight vector;

defining matrix Φ as $\Phi = U^\dagger\, diag(\tilde{\lambda}^1,\ldots,\tilde{\lambda}^M)\, U$, where *diag* indicates that the various $\tilde{\lambda}$ are arranged as the elements of the main diagonal of matrix Φ;

wherein each column of matrix Φ is used as a normalized weight vector indicated by $\Phi = [z_1,\ldots, z_N]$ and said normalized weight vectors are made up of individual normalized weights z, $z_i = [z_{i1},\ldots,z_{iN}]$, where i s an integer ranging from 1 to N;
developing unnormalized weight vector $w_i = [w_{i1},\ldots, w_{iN}]$, with each of said Weights therein being $\sqrt{\tilde{\lambda}^i} z_{ij}$, where j is an integer ranging from 1 to N.

Patentansprüche

1. Verfahren zum Senden von Signalen in einem Kommunikationssystem, das einen Sender mit N Sendeantennen hat, die über einen Vorwärts-Kanal an einen Empfänger senden, der L Empfangsantennen hat, und einen Rückkanal zur Kommunikation vom Empfänger zum Sender aufweist, wobei eine Korrelation der Signale vorhanden sein kann, die von zwei oder mehreren der L Empfangsantennen empfangen werden, wobei das Verfahren folgende Schritte umfasst:

Feststellen der Anzahl unabhängiger Signale, die von den N Sendeantennen zu den L Empfangsantennen gesendet werden können;
aus einem Datenstrom Erzeugen eines Unter-Datenstromes, der für jedes aus der Anzahl unabhängiger Signale zu senden ist, das von den N Sendeantennen an die L Empfangsantennen gesendet werden kann;

wobei das Verfahren **GEKENNZEICHNET ist durch**:

Gewichtung jedes der Unter-Datenströme mit N Gewichten, ein Gewicht für jede der N Sendeantennen, wobei die Gewichte von dem Sender als Funktion der Kanal-Information und einer Störungs-Kovarianzmatrix bestimmt werden, um N gewichtete Unter-Datenströme pro Unter-Datenstrom zu erzeugen;
Kombinieren eines der gewichteten Unter-Datenströme, der aus jedem der Unter-Datenströme für jede der Sendeantennen erzeugt wird, um für jede der Sendeantennen ein Sendesignal zu erzeugen.

2. Verfahren, wie in Anspruch 1 definiert, das ferner den Schritt des Sendens des Sendesignals von einer entsprechenden der Antennen umfasst.

3. Verfahren, wie in Anspruch 1 definiert, das ferner den Schritt des Empfangens der Gewichte über den Rückkanal umfasst.

4. Verfahren, wie in Anspruch 1 definiert, wobei die Kanal-Information und die Störungs-Kovarianzmatrix durch den Sender vom Empfänger über den Rückkanal empfangen werden.

5. Verfahren, wie in Anspruch 1 definiert, wobei die Gewichte durch Lösen einer Matrix-Gleichung $H^{\dagger}(K^N)H = U^{\dagger}A^2U$ bestimmt werden, wobei:

H eine Matrix des Kanal-Frequenzgangs ist,
$H^{\dagger}$ die konjugierte transponierte Matrix der Matrix des Kanal-Frequenzgangs H ist,
K^N die Störungs-Kovarianzmatrix ist,
U eine Einheitsmatrix ist, von der jede Spalte ein Eigenvektor von $H^{\dagger}(K^N)H$ ist,
A eine Diagonalmatrix ist, die als $A = \mathrm{diag}(\lambda^1, ..., \lambda^M)$ definiert ist, wobei $\lambda^1, ..., \lambda^M$ jeweils Eigenwerte von $H^{\dagger}(K^N)H$ sind, wobei M die maximale Anzahl von von Null verschiedenen Eigenwerten ist, die der Anzahl der unabhängigen Signale entspricht, und
$U^{\dagger}$ die konjugierte transponierte Matrix der Matrix U ist;
Füllen ("Water-Filling") der Eigenwerte λ durch Lösen des Gleichungssystems

$$\overline{\lambda}^k = \left(\nu - \frac{1}{(\lambda^k)^2}\right)^+ \quad \text{und} \quad \sum_k \overline{\lambda}^k = P, \quad \text{für}$$

ν, wobei
k ein ganzzahliger Index ist, der im Bereich von 1 bis M liegt,
P die gesendete Leistung ist,
+ ein Operator ist, der Null 0 zurückliefert, wenn sein Argument negativ ist und das Argument selbst zurückliefert, wenn es positiv ist, und
jedes λ eine Zwischen-Variable ist, die eine Leistung für jeden Gewichts-Vektor darstellt;
Definieren der Matrix Φ als $\Phi = U^{\dagger}\mathrm{diag}(\overline{\lambda}^1, ..., \overline{\lambda}^M)U$, wobei diag anzeigt, dass die verschiedenen λ als Elemente der Hauptdiagonalen der Matrix Φ angeordnet sind;

wobei jede Spalte der Matrix Φ als normierter Gewichtsvektor benutzt wird, der durch $\Phi = [z_1, ..., Z_N]$ **gekennzeichnet** ist, und die normierten Gewichtsvektoren aus einzelnen normierten Gewichten z gebildet werden, $z_i = [z_{i1}, ..., Z_{iN}]$, wobei i eine ganze Zahl im Bereich von 1 bis N ist;
Entwickeln eines nicht normierten Gewichtsvektors $w_i = [w_{i1}, ..., w_{iN}]$, wobei jedes der Gewichte $\sqrt{\overline{\lambda}^i}\, z_{ij}$ ist, wobei j eine ganze Zahl im Bereich von 1 bis N ist.

6. Vorrichtung zum Senden von Signalen in einem Kommunikationssystem, das einen Sender mit N Sendeantennen (107) hat, die über einen Vorwärts-Kanal an einen Empfänger senden, der L Empfangsantennen (201) hat, und einen Rückkanal zur Kommunikation vom Empfänger zum Sender aufweist, wobei eine Korrelation der Signale vorhanden sein kann, die von zwei oder mehreren der L Empfangsantennen empfangen werden, wobei die Vorrichtung folgendes umfasst:

Einrichtungen zum Feststellen (105, 101) der Anzahl unabhängiger Signale, die von den N Sendeantennen zu den L Empfangsantennen gesendet werden können;
Einrichtungen, um aus einem Datenstrom einen Unter-Datenstrom zu erzeugen (101), der für jedes aus der Anzahl unabhängiger Signale zu senden ist, das von den N Sendeantennen an die L Empfangsantennen gesendet werden kann;

wobei die Vorrichtung **GEKENNZEICHNET ist durch**:

Einrichtungen zur Gewichtung (113) jedes der Unter-Datenströme mit N Gewichten, ein Gewicht für jede der N Sendeantennen, wobei die Gewichte von der Vorrichtung zum Senden von

Signalen als Funktion der Information über den Vorwärts-Kanal und einer Störungs-Kovarianzmatrix bestimmt werden, um N gewichtete Unter-Datenströme pro Unter-Datenstrom zu erzeugen;
Einrichtungen zum Kombinieren (111) eines der gewichteten Unter-Datenströme, der aus jedem der Unter-Datenströme für jede der Antennen erzeugt wird, um für jede Antenne ein Sendesignal zu erzeugen.

7. Vorrichtung, wie in Anspruch 6 definiert, wobei der Sender Einrichtungen zum Entwickeln der Gewichte (105) umfasst.

8. Vorrichtung, wie in Anspruch 6 definiert, wobei der Sender Einrichtungen zum Speichern der Gewichte (105) umfasst.

9. Vorrichtung, wie in Anspruch 6 definiert, wobei der Empfänger Einrichtungen zum Entwickeln der Gewichte (209) umfasst.

10. Sender zum Senden von Signalen in einem Kommunikationssystem, das einen Sender mit N Sendeantennen (107) hat, die über einen Vorwärts-Kanal an einen Empfänger senden, der L Empfangsantennen hat, und einen Rückkanal zur Kommunikation vom Empfänger zum Sender aufweist, wobei eine Korrelation der Signale vorhanden sein kann, die von zwei oder mehreren der L Empfangsantennen (201) empfangen werden, wobei der Sender folgendes umfasst:

Einen Demultiplexer (101), um aus einem Datenstrom einen Unter-Datenstrom zu erzeugen, der für jedes aus der Anzahl unabhängiger Signale zu senden ist, das von den N Sendeantennen an die L Empfangsantennen gesendet werden kann;

wobei der Sender **GEKENNZEICHNET ist durch**:

Multiplizierer (113) zur Gewichtung jedes der Unter-Datenströme mit N Gewichten, ein Gewicht für jede der N Sendeantennen, wobei die Gewichte von dem Sender als Reaktion auf eine Abschätzung einer Störungs-Kovarianzmatrix und einer Abschätzung des Frequenzgangs des Vorwärts-Kanals zwischen dem Sender und dem Empfänger bestimmt werden, um N gewichtete Unter-Datenströme pro Unter-Datenstrom zu erzeugen; und
Addierer (111) zum Kombinieren eines der gewichteten Unter-Datenströme, der aus jedem der Unter-Datenströme für jede der Antennen erzeugt wird, um für jede der Sendeantennen ein Sendesignal zu erzeugen.

11. Sender, wie in Anspruch 10 definiert, der ferner einen Digital-/Analog-Wandler (115) zur Wandlung jedes der kombinierten gewichteten Unter-Datenströme enthält.

12. Sender, wie in Anspruch 10 definiert, der ferner einen Aufwärts-Wandler (117) zur Umwandlung der Funkfrequenzen jedes der analog-gewandelten kombinierten gewichteten Unter-Datenströme enthält.

13. Sender, wie in Anspruch 10 definiert, wobei die Abschätzung der Störungs-Kovarianzmatrix und die Abschätzung des Frequenzgangs des Vorwärts-Kanals durch den Sender über den Rückkanal vom Empfänger empfangen werden.

14. Sender, wie in Anspruch 10 definiert, wobei die Gewichte in dem Empfänger bestimmt und über den Rückkanal zum Sender gesendet werden.

15. Sender, wie in Anspruch 10 definiert, wobei die Gewichte durch Lösen einer Matrix-Gleichung $H^{\dagger}(K^N) H = U^{\dagger}A^2U$ bestimmt werden, wobei:

H eine Matrix des Kanal-Frequenzgangs ist,
$H^{\dagger}$ die konjugierte transponierte Matrix der Matrix des Kanal-Frequenzgangs H ist,
K^N die Störungs-Kovarianzmatrix ist,
U eine Einheitsmatrix ist, von der jede Spalte ein Eigenvektor von $H^{+}(K^N)H$ ist,
A eine Diagonalmatrix ist, die als $A = \mathrm{diag}(\lambda^1, ..., \lambda^M)$ definiert ist, wobei $\lambda^1, ..., \lambda^M$ jeweils Eigenwerte von $H^{\dagger}(K^N)H$ sind, wobei M die maximale Anzahl von von Null verschiedenen Eigenwerten ist, die der Anzahl der unabhängigen Signale entspricht, und
$U^{\dagger}$ die konjugierte transponierte Matrix der Matrix U ist;
Füllen ("Water-Filling") der Eigenwerte λ durch Lösen des Gleichungssystems

$$\overline{\lambda}^k = (\nu - \frac{1}{(\lambda^k)^2})^+ \text{ und } \sum_k \overline{\lambda}^k = P \text{, für } \nu,$$

wobei
k ein ganzzahliger Index ist, der im Bereich von 1 bis M liegt,
P die gesendete Leistung ist,
+ ein Operator ist, der Null 0 zurückliefert, wenn sein Argument negativ ist und das Argument selbst zurückliefert, wenn es positiv ist, und
jedes λ eine Zwischen-Variable ist, die eine Leistung für jeden Gewichts-Vektor darstellt;
Definieren der Matrix Φ als $\Phi = U^{\dagger}\mathrm{diag}\,(\overline{\lambda}^1, ..., \overline{\lambda}^M)\, U$, wobei diag anzeigt, dass die verschiedenen $\overline{\lambda}$ als Elemente der Hauptdiagonalen der Matrix Φ angeordnet sind;

wobei jede Spalte der Matrix Φ als normierter Gewichtsvektor benutzt wird, der durch $\Phi = [z_1, ..., Z_N]$ **gekennzeichnet** ist, und die normierten Gewichtsvektoren aus einzelnen normierten Gewichten z gebildet werden, $z_i = [z_{i1},..., z_{iN}]$, wobei i eine ganze Zahl im Bereich von 1 bis N ist;
Entwickeln eines nicht normierten Gewichtsvektors $w_i = [w_{i1}, ..., w_{iN}]$, wobei jedes der Gewichte $\sqrt{\bar{\lambda}^i}\, z_{ij}$ ist, wobei j eine ganze Zahl im Bereich von 1 bis N ist.

16. Sender, wie in Anspruch 10 definiert, wobei der Sender und der Empfänger unter Verwendung von Zeitmultiplex TDD miteinander kommunizieren und die Gewichte in dem Sender unter Verwendung einer Abschätzung des Frequenzgangs des Vorwärts-Kanals bestimmt werden, die von Empfänger des Rückkanals für den Sender bestimmt wird.

17. Empfänger zur Verwendung in einem MIMO-System, umfassend:

L Antennen (201);
L Abwärts-Wandler (203); und
einen Abschätzer zur Bestimmung einer Abschätzung einer Störungs-Kovarianzmatrix für einen Vorwärts-Kanal, der von dem Empfänger empfangen wird;

wobei der Empfänger **GEKENNZEICHNET ist durch**:

Einrichtungen zum Senden (211) von Informationen zur Verwendung **durch** einen Sender bei der Gewichtung von Signalen, die an N Sendeantennen des Senders geliefert werden, wobei die Information eine Funktion der Störungs-Kovarianzmatrix ist.

18. Empfänger, wie in Anspruch 17 definiert, wobei die Information die Störungs-Kovarianzmatrix ist.

19. Empfänger, wie in Anspruch 17 definiert, der ferner einen Abschätzer (207) enthält, um eine Abschätzung eines Kanal-Frequenzgangs für einen Vorwärts-Kanal zu bestimmen, der von dem Empfänger empfangen wird, wobei die Information die Abschätzung eines Kanal-Frequenzganges für einen Vorwärts-Kanal und die Störungs-Kovarianzmatrix enthält.

20. Empfänger, wie in Anspruch 17 definiert, der ferner folgendes umfasst:

einen Abschätzer (207) zur Bestimmung einer Abschätzung einer Störungs-Kovarianzmatrix für einen Vorwärts-Kanal, der von dem Empfänger empfangen wird; und
einen Gewichts-Berechner (209) zur Berechnung von Gewichten zur Verwendung durch einen Sender des Vorwärts-Kanals zum Senden von Unter-Datenströmen an den Empfänger als Funktion der Abschätzung einer Störungs-Kovarianzmatrix für einen Vorwärts-Kanal, der von dem Empfänger empfangen wird, und der Abschätzung eines Kanal-Frequenzgangs für einen Vorwärts-Kanal, der von dem Empfänger empfangen wird;

wobei die Informationen die Gewichte sind.

21. Empfänger, wie in Anspruch 20 definiert, wobei die Gewichte in dem Gewichts-Berechner bestimmt werden durch
Lösen einer Matrix-Gleichung $H^\dagger(K^N)H = U^\dagger A^2 U$, wobei:

H eine Matrix des Kanal-Frequenzgangs ist,
$H^\dagger$ die konjugierte transponierte Matrix der Matrix des Kanal-Frequenzgangs H ist,
K^N die Störungs-Kovarianzmatrix ist,
U eine Einheitsmatrix ist, von der jede Spalte ein Eigenvektor von $H^\dagger(K^N)H$ ist,
A eine Diagonalmatrix ist, die als $A = \mathrm{diag}(\lambda^1, ..., \lambda^M)$ definiert ist, wobei $\lambda^1, ..., \lambda^M$ jeweils Eigenwerte von $H^\dagger(K^N)H$ sind, wobei M die maximale Anzahl von von Null verschiedenen Eigenwerten ist, die der Anzahl der unabhängigen Signale entspricht, und
$U^\dagger$ die konjugierte transponierte Matrix der Matrix U ist;
Füllen ("Water-Filling") der Eigenwerte λ durch Lösen des Gleichungssystems

$$\bar{\lambda}^k = \left(\nu - \frac{1}{(\lambda^k)^2}\right)^+ \text{ und } \sum_k \bar{\lambda}^k = P \text{, für } \nu,$$

wobei
k ein ganzzahliger Index ist, der im Bereich von 1 bis M liegt,
P die gesendete Leistung ist,
+ ein Operator ist, der Null (0) zurückliefert, wenn sein Argument negativ ist und das Argument selbst zurückliefert, wenn es positiv ist, und
jedes λ eine Zwischen-Variable ist, die eine Leistung für jeden Gewichts-Vektor darstellt;
Definieren der Matrix Φ als $\Phi = U^\dagger \mathrm{diag}\,(\bar{\lambda}^1, ..., \bar{\lambda}^M)\, U$, wobei diag anzeigt, dass die verschiedenen λ als Elemente der Hauptdiagonalen der Matrix Φ angeordnet sind;

wobei jede Spalte der Matrix Φ als normierter Gewichtsvektor benutzt wird, der durch $\Phi = [z_1, ..., Z_N]$ **gekennzeichnet** ist, und die normierten Gewichts-

vektoren aus einzelnen normierten Gewichten z gebildet werden, $z_i = [z_{i1}, ..., z_{iN}]$, wobei i eine ganze Zahl im Bereich von 1 bis N ist;
Entwickeln eines nicht normierten Gewichtsvektors $w_i = [w_{i1}, ..., w_{iN}]$, wobei jedes der Gewichte $\sqrt{\overline{\lambda}^i}\, z_{ij}$ ist, wobei j eine ganze Zahl im Bereich von 1 bis N ist.

Revendications

1. Procédé destiné à transmettre des signaux dans un système de communication ayant un émetteur avec N antennes de transmission transmettant par une voie aval vers un récepteur ayant L antennes de réception et une voie inverse pour communiquer dudit récepteur audit émetteur dans lequel il peut exister une corrélation dans les signaux reçus par au moins deux desdits L antennes de réception, le procédé comprenant les étapes consistant à :

déterminer le nombre de signaux indépendants qui peuvent être transmis desdites N antennes de transmission auxdites L antennes de réception ;
créer, à partir d'un flot de données, un sous-flot de données destiné à être transmis pour chaque nombre de signaux indépendants qui peuvent être transmis desdites N antennes de transmission auxdites L antennes de réception:

le procédé étant **CARACTERISE en ce que** chacun desdits sous-flots est pondéré avec N poids, un poids pour chacune desdites N antennes de transmission, lesdits poids étant déterminés par ledit émetteur en fonction des informations de la voie et d'une matrice de covariance d'interférences, pour produire N sous-flots pondérés pour chaque sous-flot ;
combiner l'un desdits sous-flots pondérés produit à partir de chacun desdits sous-flots pour chacune desdites antennes de transmission pour produire un signal de transmission pour chacune desdites antennes de transmission.

2. Procédé selon la revendication 1 comprenant en outre l'étape consistant à transmettre ledit signal de transmission à partir de l'une desdites antennes respectives.

3. Procédé selon la revendication 1 comprenant en outre l'étape consistant à transmettre lesdits poids via ladite voie inverse.

4. Procédé selon la revendication 1, dans lequel lesdites informations de la voie et de ladite matrice de covariance d'interférences sont reçues par ledit émetteur dudit récepteur via ladite voie inverse.

5. Procédé selon la revendication 1, dans lequel lesdits poids sont déterminés en résolvant une équation de matrice $H^t(K^N)H = U^t \Lambda^2 U$ où :

H est une matrice de réponse de la voie,
H^t est une transposée conjuguée de ladite matrice de réponse de la voie H,
K^N est la matrice de covariance d'interférences,
U est une matrice unitaire, dont chaque colonne est un vecteur propre de $H^t(K^N)H$,
Λ est une matrice diagonale définie sous la forme $\Lambda = diag(\lambda^1,....,\lambda^M)$, où $\lambda^1,...., \lambda^M$ sont chacun des valeurs propres $H^t(K^N)H$, M étant le nombre maximum de valeurs propres différentes de zéro, qui correspond au nombre desdits signaux indépendants, et
U^t est la transposée conjuguée de la matrice U;
répartissant lesdites valeurs propres λ en fonction d'un «niveau d'eau » en résolvant les équations simultanées

$$\overline{\lambda}^k = (v - \frac{1}{(\lambda^k)^2}) \text{ et } \sum_k \overline{\lambda}^k = P ,$$

pour v, où:

k est un indice de nombre entier qui se situe dans la plage de 1 à M,
P est la puissance transmise,
+ est un opérateur qui renvoie zéro 0 quand son argument est négatif, et renvoie l'argument lui-même quand il est positif, et
chaque $\overline{\lambda}$ est une variable intermédiaire représentative d'une puissance pour chaque vecteur de pondération ;

définissant la matrice Φ sous la forme $\Phi = U^t diag(\lambda^i,..., \lambda^M)U$, où diag indique que les différents $\overline{\lambda}$ sont agencés comme les éléments de la diagonale principale de la matrice Φ ;

dans lequel chaque colonne de la matrice Φ est utilisée comme un vecteur de pondération normalisé indiqué par $\Phi = [z_i,...,z_N]$ et lesdits vecteurs de pondération normalisés sont constitués de différents poids normalisés z, $z_i=[z_{i1},...,z_{iN}]$, où i est un nombre entier se situant dans la plage de 1 à N ;
développer un vecteur de pondération non normalisé $w_i=[w_{i1},..., w_{iN}]$, chacun desdits poids à l'intérieur

étant $\sqrt{\overline{\lambda}^i}\, z_{ij}$, où j est un nombre entier se situant dans la plage de 1 à N.

6. Appareil destiné à transmettre des signaux dans un système de communication ayant un émetteur avec N antennes de transmission (107) transmettant par une voie aval à un récepteur ayant L antennes de réception (201) et une voie inverse pour communiquer dudit récepteur audit émetteur, dans lequel il peut exister une Corrélation dans les signaux reçus par au moins deux desdites L antennes de réception, l'appareil comprenant :

   des moyens permettant de déterminer (105, 101) le nombre de signaux indépendants qui peuvent être transmis desdites N antennes de transmission auxdites L antennes de réception ;
   des moyens permettant de créer (101), à partir d'un flot de données, un sous-flot de données destiné à être transmis pour chaque nombre de signaux indépendants qui peuvent être transmis desdites N antennes de transmission auxdites L antennes de réception ;

   ledit appareil étant **CARACTERISE en ce que** des moyens sont destinés à pondérer (113) chacun desdits sous-flots avec N poids, un poids pour chacune desdites antennes de transmission, lesdits poids étant déterminés par ledit appareil destiné à transmettre des signaux en fonction des informations sur ladite voie aval et une matrice de covariance d'interférences, pour produire N sous-flots pondérés pour chaque sous-flot ;
   des moyens destinés à combiner (111) l'un desdits sous-flots pondérés produits à partir de chacun desdits sous-flots pour chacune desdites antennes pour produire un signal de transmission pour chaque antenne.

7. Appareil selon la revendication 6, dans lequel ledit émetteur comprend des moyens destinés développer lesdits poids (105).

8. Appareil selon la revendication 6, dans lequel ledit émetteur comprend des moyens destinés à stocker lesdits poids (105).

9. Appareil selon la revendication 6, dans lequel ledit récepteur comprend des moyens destinés développer lesdits poids (209).

10. Emetteur destiné à transmettre des signaux dans un système de communication ayant un émetteur avec N antennes de transmission (107) pour transmettre par une voie aval à un récepteur ayant L antennes de réception et une voie inverse pour communiquer dudit récepteur audit émetteur, dans lequel il peut exister une corrélation dans les signaux reçus par au moins deux desdites L antennes de réception (201), l'émetteur comprenant :

   un démultiplexeur (101) destiné à créer, à partir d'un flot de données, un sous-flot de données destiné à être transmis pour chaque nombre de signaux indépendants qui peuvent être transmis desdites N antennes de transmission auxdites L antennes de réception ;

   ledit émetteur étant **CARACTERISE en ce que** des multiplicateurs (113) sont destinés à pondérer chacun desdits sous-flots avec N poids, un poids pour chacune desdites N antennes de transmission, dans lequel lesdits poids sont déterminés dans ledit émetteur en réaction à une évaluation de matrice de covariance d'interférences et une évaluation de la réponse de la voie aval entre ledit émetteur et ledit récepteur, pour produire N sous-flots pondérés pour chaque sous-flot ; et
   des additionneurs (111) destinés à combiner l'un desdits sous-flots pondérés produits à partir de chacun desdits sous-flots pour chacune desdites antennes pour produire un signal de transmission pour chacune desdites antennes.

11. Emetteur selon la revendication 10 comprenant en outre un convertisseur numérique-analogique (115) destiné à convertir chacun desdits sous-flots pondérés combinés.

12. Emetteur selon la revendication 10 comprenant en outre un convertisseur à fréquence ascendante (117) destiné à convertir en fréquences radioélectriques chacun desdits sous-flots pondérés combinés convertis en sous-flots analogiques.

13. Emetteur selon la revendication 10, dans lequel ladite évaluation de la matrice de covariance d'interférences et ladite évaluation de la réponse de la voie aval sont reçues par ledit émetteur dudit récepteur par ladite voie inverse.

14. Emetteur selon la revendication 10, dans lequel lesdits poids sont déterminés dans ledit récepteur et sont transmis audit émetteur par ladite voie inverse.

15. Emetteur selon la revendication 10, dans lequel lesdits poids sont déterminés en résolvant une équation de *matrice* $H^t\,(K^N)^H = U^t \Lambda^2 U$ où
   H est une matrice de réponse de la voie,
   H^t est une transposée conjuguée de la matrice de réponse de la voie H,
   K^N est la matrice de covariance d'interférences,
   U est une matrice unitaire, dont chaque colonne est

un vecteur propre de $H^{\dagger}(K^N)H$,
Λ est une matrice diagonale définie sous la forme $\Lambda = diag(\lambda^t,....\lambda^M)$, où λ^1 ... , λ^M sont chacun des valeurs propres de $H^t(K^N)H$, M étant le nombre maximum de valeurs propres différentes de zéro, qui correspond au nombre desdits signaux indépendants, et
U^t est la transposée conjuguée de la matrice U ;
répartissant l'énergie desdites valeurs propres λ en fonction d'un « niveau d'eau » en résolvant les équations simultanées $\overline{\lambda}^k = (\nu - \frac{1}{(\lambda^k)^2})$ et $\sum_k \overline{\lambda}^k = P$, pour v, où :

k est un indice de nombre entier qui se situe dans la plage de 1 à M,
P est la puissance transmise,
+ est un opérateur qui renvoie zéro 0 quand son argument est négatif, et renvoie l'argument lui-même quand il est positif, et
chaque $\overline{\lambda}$ est une variable intermédiaire représentative d'une puissance pour chaque vecteur de pondération ;

définissant la matrice Φ sous la forme $\Phi = U^t\ diag(\overline{\lambda}^t,..., \overline{\lambda}^M)U$, où diag indique que les différents $\overline{\lambda}$ sont agencés comme les éléments de la diagonale principale de la matrice Φ;
dans lequel chaque colonne de la matrice est utilisée comme un vecteur de pondération normalisé indiqué par $\Phi = [z_1,..., z_N]$ et lesdits vecteurs de pondération normalisés sont constitués de différents poids normalisés z, $z_i = [z_{i1},....., z_{iN}]$, où i est un nombre entier se situant dans la plage de 1 à N ;
développer le vecteur de pondération non normalisé $w_i = [w_{i1},...., w_{iN}]$, chacun desdits poids à l'intérieur étant $\sqrt{\overline{\lambda}^i}\, z_j$, où j est un nombre entier se situant dans la plage de 1 au N.

16. Emetteur selon la revendication 10, dans lequel ledit émetteur et ledit récepteur communiquent à l'aide d'un multiplexage par répartition dans le temps TDD et lesdits poids sont déterminés dans ledit émetteur à l'aide d'une évaluation de la réponse de la voie aval qui est déterminée par un récepteur de ladite liaison inverse pour ledit émetteur.

17. Récepteur destiné à être utilisé dans un système MIMO, comprenant :

L antennes (201) ;
L convertisseurs à fréquence descendante (201) ; et
un évaluateur destiné à déterminer une évaluation d'une matrice de covariance d'interférences pour une voie aval étant reçue par ledit récepteur ;

ledit récepteur étant **CARACTERISE en ce que** des moyens sont destinés à transmettre (211) des informations destinées à être utilisées par un émetteur dans les signaux de pondération fournis à N antennes de transmission dudit émetteur, lesdites informations étant fonction de ladite matrice de covariance d'interférences.

18. Récepteur selon la revendication 17, dans lequel lesdites informations sont ladite matrice de covariance d'interférences.

19. Récepteur selon la revendication 17 comprenant en outre un évaluateur (207) destiné à déterminer une évaluation d'une réponse de la voie pour une voie aval reçue par ledit récepteur, dans lequel lesdites informations incluent ladite évaluation d'une réponse de la voie pour une voie aval et ladite matrice de covariance d'interférences.

20. Récepteur selon la revendication 17 comprenant en outre :

un évaluateur (207) destiné à déterminer une évaluation d'une matrice de covariance d'interférences pour une voie aval reçue par ledit récepteur, et
un calculateur de poids (209) destiné à calculer des poids destinés à être utilisés par un émetteur de ladite voie aval pour transmettre les sous-flots de données audit récepteur en fonction de ladite évaluation d'une matrice de covariance d'interférences pour une voie aval reçue par ledit récepteur et ladite évaluation d'une réponse de la voie pour une voie aval reçue par ledit récepteur ;

dans lequel lesdites informations sont lesdits poids.

21. Récepteur selon la revendication 20, dans lequel lesdits poids sont déterminés dans ledit calculateur en
résolvant une équation de matrice $H^t(K^N)H = U^t\Lambda^2 U$ où:

H est une matrice de réponse de la voie,
$H^{\dagger}$ est une transposée conjuguée de ladite matrice de réponse de la voie H,
K^N est la matrice de covariance d'interférences,
U est une matrice unitaire, dont chaque colonne est un vecteur propre de $H^t(K^N)H$,
Λ est une matrice diagonale définie sous la for-

me $\Lambda = diag(\lambda^1,...,\lambda^M)$, où $\lambda^1,...,\lambda^M$ sont chacun des valeurs propres de $H^t(K^N)H$, M étant le nombre maximum de valeurs propres différentes de zéro, qui correspond au nombre desdits signaux indépendants, et

U^t est la transposée conjuguée de la matrice U ; répartissant lesdites valeurs propres λ en fonction d'un « niveau d'eau » en résolvant les équations simultanées

$$\overline{\lambda}^k = (\nu - \frac{1}{(\lambda^k)^2}) \text{ et } \sum_k \overline{\lambda}^k = P ,$$

pour v, où :

k est un indice de nombre entier qui se situe dans la plage de 1 à M,
P est la puissance transmise,
+ est un opérateur qui renvoie zéro 0 quand son argument est négatif, et renvoie l'argument lui-même quand il est positif, et
chaque λ est une variable intermédiaire représentative d'une puissance pour chaque vecteur de pondération ;

définissant la matrice Φ sous la forme $\Phi = U^t (\overline{\lambda}^i,...,\overline{\lambda}^M) U$, où diag indique que les différents $\overline{\lambda}$ sont agencés comme les éléments de la diagonale principale de la matrice Φ ;

dans lequel chaque colonne de la matrice Φ est utilisée comme un vecteur de pondération normalisé indiqué par $\Phi = [z_i,..., z_N]$ et lesdits vecteurs de pondération normalisés sont constitués de différents poids normalisés z, $z_i = [z_{i1},...,z_{iN}]$, où i est un nombre entier se situant dans la plage de 1 à N.

FIG. 1

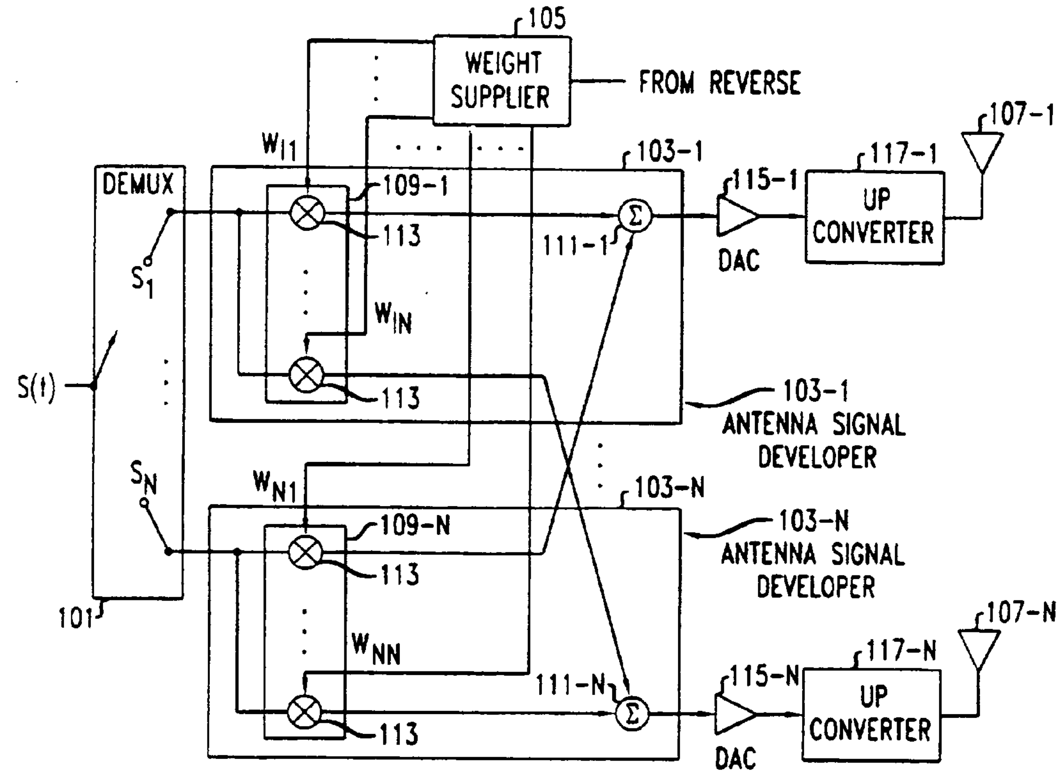

105
WEIGHT SUPPLIER
FROM REVERSE
DEMUX
S(t)
S_1
S_N
W_{11}
W_{1N}
W_{N1}
W_{NN}
101
103-1
109-1
113
111-1
115-1
DAC
117-1
UP CONVERTER
107-1
103-1
ANTENNA SIGNAL DEVELOPER
103-N
ANTENNA SIGNAL DEVELOPER
109-N
111-N
115-N
117-N
107-N

FIG. 2

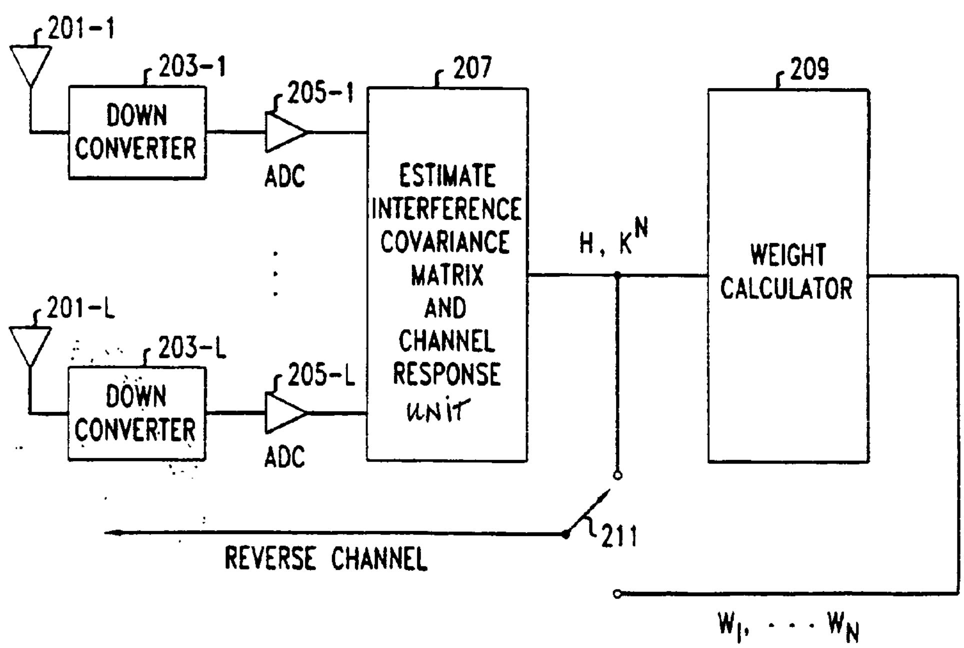

201-1
203-1
DOWN CONVERTER
205-1
ADC
207
ESTIMATE INTERFERENCE COVARIANCE MATRIX AND CHANNEL RESPONSE unit
H, K^N
209
WEIGHT CALCULATOR
201-L
203-L
205-L
211
REVERSE CHANNEL
$W_1, \cdots W_N$

FIG. 3

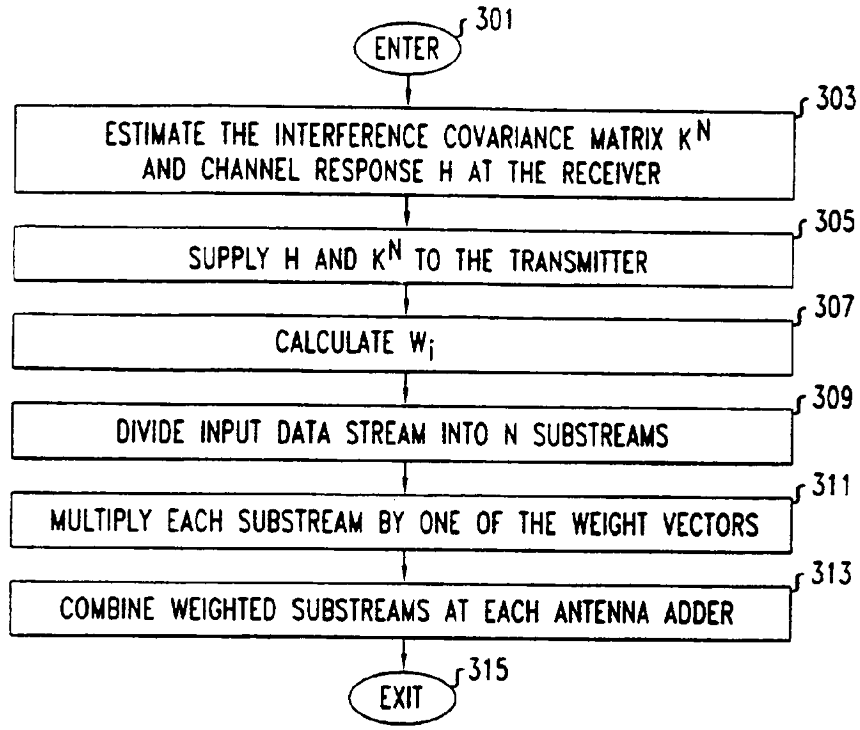
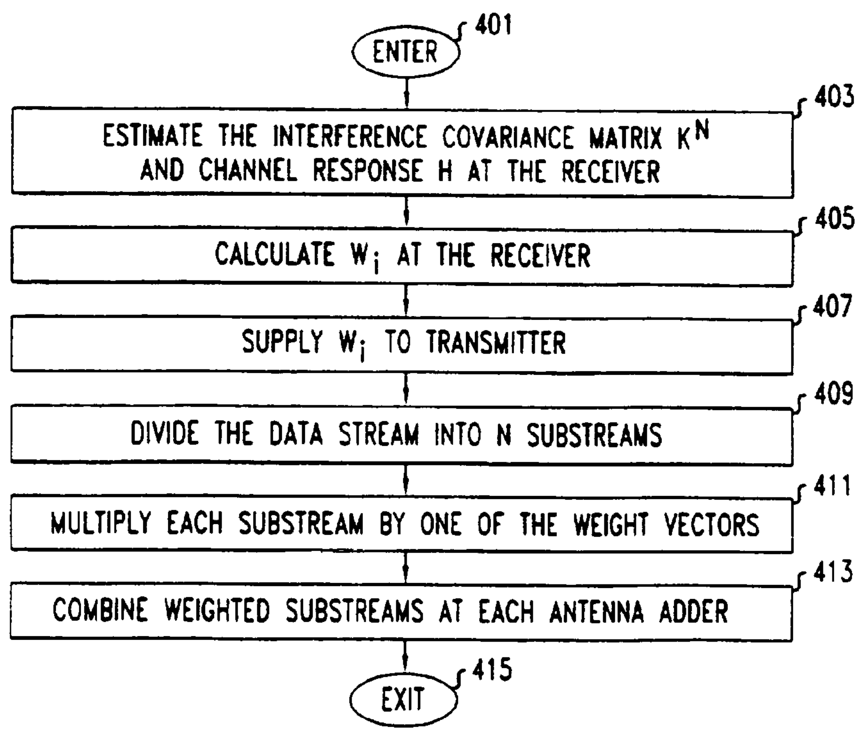

ENTER
301
ESTIMATE THE INTERFERENCE COVARIANCE MATRIX K^N AND CHANNEL RESPONSE H AT THE RECEIVER
303
SUPPLY H AND K^N TO THE TRANSMITTER
305
CALCULATE W_i
307
DIVIDE INPUT DATA STREAM INTO N SUBSTREAMS
309
MULTIPLY EACH SUBSTREAM BY ONE OF THE WEIGHT VECTORS
311
COMBINE WEIGHTED SUBSTREAMS AT EACH ANTENNA ADDER
313
EXIT
315

FIG. 4


ENTER
401
ESTIMATE THE INTERFERENCE COVARIANCE MATRIX K^N AND CHANNEL RESPONSE H AT THE RECEIVER
403
CALCULATE W_i AT THE RECEIVER
405
SUPPLY W_i TO TRANSMITTER
407
DIVIDE THE DATA STREAM INTO N SUBSTREAMS
409
MULTIPLY EACH SUBSTREAM BY ONE OF THE WEIGHT VECTORS
411
COMBINE WEIGHTED SUBSTREAMS AT EACH ANTENNA ADDER
413
EXIT
415

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- WO 9809381 A **[0003]**